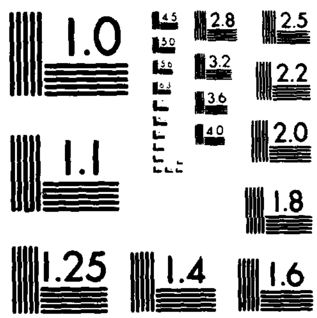
AD-A086 688 COLUMBIA UNIV NEW YORK DEPT OF ELECTRICAL ENGINEERIN--ETC F/G 20/5
HIGH POWER SUBMILLIMETER AND INFRARED RADIATION FROM INTENSE RE--ETC(U)
MAR 80 S P SCHLESINGER, T C MARSHALL F44620-75-C-0055
UNCLASSIFIED AFOSR-TR-80-0545 NL

END
DATE FILMED
8-80
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AFOSR-TR- 80-0545

ADA086688

Final Report

to

LEVEL II

Air Force Office of Scientific Research

"High Power Submillimeter and Infrared Radiation from Intense Relativistic Electron Beams"

Research Conducted Under: Contract F44620-75-C-0055

Period Covered: 1 January 1975 - 31 December 1979

Principal Investigator:

S.P. Schlesinger
Professor of Electrical Engineering

Co-Principal Investigators:

T.C. Marshall
Professor of Applied Physics

P. Diament
Professor of Electrical Engineering

I. Introduction:

The submission of this report marks the end of the first phase of research conducted by the Principal Investigators* on "High Power Submillimeter and Far Infrared Radiation from Intense Relativistic Electron Beams" carried out during the 5-year period 1975-1979 under Contract F 44620-75-C-0055. Phase Two of this research, continuing under grant AFOSR 80-0118, will be directed toward a detailed study of the collective free electron laser developed by this group, with the experimental program utilizing the new up-graded accelerator purchased with special supplementary funds as supplied by the Air Force under the F44620-75-C-0055 contract. (The Physics International Pulserad 220 unit (1 MeV, 20 KA, 100+ nsec) has been installed and is currently undergoing initial testing.)

Part II of this report covers the period 1 Jan. 1979 - 31 Dec. 1979 and is presented for the sake of completeness in the same format as the previous Interim Reports submitted after each of the first 4 years of this contract. Part III is a concise statement of accomplishment in the form of a Bibliographical Summary, detailing in roughly chronological order all papers published during the 5-year contract period.

* **Included also is a summary of theoretical studies conducted by Professor S. Johnston (Section II-B-2).**

II. Interim Report: 1 Jan. 1979 - 31 Dec. 1979

A. Experimental Research

Experimental work this past year, continued on our old Pulserad until Nov. 1979, was oriented towards laying the groundwork for the new Pulserad 220 facility mentioned in Part I. Funds for the latter were awarded in Spring 1979, and the machine was completed and tested within specifications in San Leandro in December, 1979.

A series of experiments was performed to test the dependence of superadient power generated by stimulated Raman backscattering (at $\lambda_s \gtrsim 2$ mm) upon ripple-field amplitude and length. We can now pulse our "undulators" (or "wigglers") to kilogauss amplitude at ripple period of $\ell = 8$ mm. However, power emitted from the shell-beam saturated before this point. In anticipation of future experiments which may call for a low total beam current of high density,we also tried a configuration of a pencil beam (dia. $\gtrsim$ 3 mm) in a 1 cm drift tube. The rippled period was $\ell = 17$ mm, provided by a pulsed bifilar helical winding. Here, a ripple field of up to 2 kG could be obtained; also, we could observe "magnetoresonance", a condition for which the effective pump frequency ($2\pi\gamma\ V_{\parallel}/\ell$) was about equal to the electron gyrofrequency (eB_z/mc). At that condition, the superadient power ($\lambda_s \gtrsim 4$ mm) decreased, either because of beam scape-off on the drift tube wall or because of beam heating. The experiments did, however, show the feasibility of pencil-beam experiments in our new facility, where $\lambda_s \sim 1$ mm is to be expected.

Experiments were also done using a distributed feedback element in the system (see diag.). The latter is a grooved coaxial element which in theory would a) replace the mirrors in a laser cavity and b) lock the cavity radiation to the mode $\lambda_s = \ell_0/2$ where ℓ_0 is the groove spacing. The grooves were square-channeled corrugations, $\lambda_s/4$ deep. Some evidence of lasing was obtained (note the pulse length of our Pulserod 105 system is 10 nsec, so lasing is out of the question in a system $\sim$ 1 m in length), but it was not reproducible. One reason for this trouble is that the tolerance on the groove is very strict: there must be less than $\lambda_s/2$ accumulated of random machining error over a grating length of $\approx$ 600 grooves to avoid destructive interference. It was decided to postpone further experiments until sometime after the installation of our new facility.

B. Theoretical Research

1. A study was conducted of the growth of circular waveguide modes by parametric coupling to cold beam waves, with field gradient effects included. A revision of a previously submitted paper on this work is in progress. Studies ancillary to some of the experimental work included an exact analysis of the fields of a bifilar helix, including all harmonics and the associated electron orbits. This showed that the electrons may strike the drift tube wall for certain applied fields, which should explain the observed drop-off in superadiant power output as the ripple field is increased. As an aid to distributed feedback experiments, exact expressions for the fields in a corrugated waveguide were derived. A major effort has been directed at means for improving the quality of the beam. Exact equilibria* of a perfectly cold beam in Brillouin flow have been examined, for both pencil-beam and annular geometry, with the integral impedance of the driving circuitry included. The purpose is to arrive at a design for launching a cold beam. One scheme under investigation is the matching of the calculated beam impedance to that of the driver. Another is to shape the cathode geometry to conform to the analytically derived electron orbits in the cold equilibrium. This work is continuing.

2. Investigation of a new operating mode has continued for low-

*III,3.

gain recycled systems (viz., the finite length plasma-modified Compton effect). Explicit cold-beam results (including a guide magnetic field) show appreciable gain from spatial transients in an intense beam, and suggest that operation in this mode may avoid the rather stringent limitation on wavelength imposed by beam energy spread for exponential-gain operation. A paper summarizing the results of this study is almost complete.

C. Publications and Talks

1. Published

a) "Spectral Properties of Stimulated Raman Radiation from an Intense Relativistic Electron Beam", R.M. Gilgenbach, T.C. Marshall and S.P. Schlesinger, Phys. Fluids 22, 971, 1979.

b) "Cyclotron Harmonic Damping in Stimulated Raman Scattering from an Intense Relativistic Electron Beam", R.M. Gilgenbach, T.C. Marshall and S.P. Schlesinger, Phys. Fluids 22, 1219, 1979.

2. To Appear

a) "The Free Electron Laser-- A High Power Sub-mm Radiation Source", T.C. Marshall, S.P. Schlesinger and D.B. McDermott, Vol. 53 of Series on Advances in Electronics & Electron Physics (Marton, ed) - Academic Press (1980).

b) "An Analysis of the Collective Free Electron Laser", T.C. Marshall and D.B. McDermott. Proc. 2nd Int'l Conf. on Energy Storage & Switching, Gordon & Breach (1980).

c) "The Collective Free Electron Laser" in "The Physics of Quantum Electronics", T.C. Marshall and D.B. McDermott. (Scully, Jacobs and Sargeant, eds) Addison Wesley, Vol.1 (1980).

3. Technical Talks

	Author	Title	Meeting	Abstract Reference
a)	Johnston	"Finite Length Theory of Collective Free Electron Lasers"	Controlled Fusion (Sherwood) Conf.	Proc. Paper 2C 22
b)	Johnston	"Finite Length Theory of Collective Free Electron Lasers"	APS Spring Meeting 4/79	Bull. APS 24, 663(1979)
c)	Marshall	"The Collective Free Electron Laser"	FEL Workshop Telluride, Colo., 8/79	Phys. Quant. Elec. (See II C 2-(c) this report)
d)	Birkett, Dworkis, Marshall, Schlesinger	"Distributed Feedback Free Electron Laser"	APS/Plasma 11/79	(Post-deadline)
e)	McDermott	"Space-charge Enchancement of Free Electron Lasers"	APS/Plasma 11/79	Bull. APS 24, 1067, (1979)
f)	Schlesinger (invited)	"Submillimeter Collective Free Electron Laser"	4th Int'l Sub-mm Conference Miami, 12/79	
g)	Marshall, McDermott	Analysis of the Collective Free Electron Laser"	"Lasers '79" Orlando, 12/79	

D. Patents

AF Invention No. 13,

"Free Electron Laser Employing an Expanded Hollow Intense Electron Beam and Periodic Radial Magnetic Field", S.P. Schlesinger, T.C. Marshall, D.B. McDermott, V.L. Granatstein, R.K. Parker and P.A. Sprangle.

(Filed U.S. Patent Office, Nov. 1979).

III. Bibliographical Summary: 1975 - 1979

1. "Relativistic Electron Beam Generated Coherent Submillimeter Wavelength, Cerenkov Radiation", J.E. Walsh, T.C. Marshall, M.R. Mross, S.P. Schlesinger, 2nd Int'l. Conf. on Submillimeter Waves, IEEE, #76, CH 1152-8 MTT, p. 130 (1976).
2. "Submillimeter Wave Generation Through Stimulated Scattering with an Intense Relativistic Electron Beam and Zero Frequency Pump", M.R. Mross, T.C. Marshall, P. Efthimion, S.P. Schlesinger, 2nd Int'l. Conf. on Submillimeter Waves, IEEE, #76, CH 1152-8 MTT, p. 128 (1976).
3. "Exact Self-Consistent Equilibria of Relativistic Electron Beams", P. Diament, Phys. Rev. Lett. 37, 168 (1976).
4. "Broad Spectral Electromagnetic Radiation Calorimeter: Centimeters to Microns", P. Efthimion, P.R. Smith, S.P. Schlesinger, Rev. Sci. Instr. 47, 1059 (1976).
5. "Generation of Coherent Cerenkov Radiation with an Intense Relativistic Electron Beam", J.E. Walsh, T.C. Marshall, S.P. Schlesinger, Physics of Fluids, 20, 709 (1977).
6. "Relativistic Electron Beam Generated Coherent Submillimeter Wavelength Cerenkov Radiation", J.E. Walsh, T.C. Marshall, M.R. Mross, and S.P. Schlesinger, IEEE Trans. MTT-25, 561 (1977).
7. "Correlation of Intense Relativistic Electron Beam Dynamics with the Operation of the Relativistic Cyclotron Maser", S. Talmadge, T.C. Marshall, S.P. Schlesinger, Physics of Fluids, 20, 974 (1977).
8. "Direct Measurement of Broad Spectral Electromagnetic Wave Energy Generated by an Intense Relativistic Electron Beam", P. Efthimion and S.P. Schlesinger, Appl. Phys. Lett. 30, 259 (1977).

9. "Stimulated Raman Scattering by an Intense Relativistic Electron Beam in a Long Rippled Magnetic Field", P. Efthimion and S.P. Schlesinger, Physical Review A., 15, 633 (1977).

10. "High Power Millimeter Radiation from an Intense Relativistic Electron Beam Device," T.C. Marshall, S. Talmadge and P. Efthimion, Appl. Phys. Lett., 31, 320 (1977).

11. "Zero Frequency Pumped Raman-Scattering by an Intense Relativistic Eletron Beam", P. Efthimion and S.P. Schlesinger, Proc. 2nd Int'l. Conf. on High Power Electron and Ion Beam Research and Technology, Cornell University, Ithaca, New York, Vol. II, 691, Oct. 1977.

12. "Millimeter Generation Through Stimulated Scattering with IREB and a Controlled Zero Frequency Pump", T.C. Marshall, F.L. Sandel and R.M. Gilgenbach, Proc. 2nd International Conference on High Power Electron and Ion Beam Research and Technology, Cornell University, Ithaca, New York, Vol. II, 697, Oct. 1977.

13. "Production of Megawatt Millimeter Radiation by Interaction of an Intense Relativistic Electron Beam and a Zero Frequency Pump", R.M. Gilgenbach, D.B. McDermott, T.C. Marshall, and S.P. Schlesinger, Proc. 3rd International Conference on Submillimeter Waves and their Applications, University of Surrey, Proc. p. 156, March 1978.

14. "An Intense Relativistic Electron Beam Raman Laser", D.B. McDermott, T.C. Marshall and S.P. Schlesinger, Comments Plasma Phys. Cont. Fusion, 3, 165, 1978.

15. "Thermal Sensitive Paper as a Diagnostic for Intense Relativistic Electron Beam Dynamics", R.M. Gilgenbach, D.B. McDermott and T.C. Marshall, Rev. Sci. Intrum. 49, 1098, 1978.

16. "High-Power Free Electron Laser Based on Stimulated Raman Back-scattering", D.B. McDermott, T.C. Marshall, S.P. Schlesinger, R.K. Parker and V.L. Granatstein, Phys. Rev. Letters, 41, 1368, 1978.

17. "Spectral Properties of Stimulated Raman Radiation from an Intense Relativistic Electron Beam", R.M. Gilgenbach, T.C. Marshall and S.P. Schlesinger, Phys. Fluids 22, 971, 1979.

18. "Cyclotron Harmonic Damping in Stimulated Raman Scattering from an Intense Relativistic Electron Beam", R.M. Gilgenbach, T.C. Marshall and S.P. Schlesinger, Phys. Fluids 22, 1219, 1979.

19. "The Free Electron Laser--A High Power Submillimeter Radiation Source", T.C. Marshall, S.P. Schlesinger and D.B. McDermott, Vol. 53 of Series on Advances in Electronics and Electron Physics (Marton, ed.) Academic Press (1980). (To Appear).

20. "An Analysis of the Collective Free Electron Laser", T.C. Marshall and D.B. McDermott, Proc. 2nd Int'l. Conf. on Energy Storage & Switching, Gordon and Breach (1980). (To Appear).

21. "The Collective Free Electron Laser", in "The Physics of Quantum Electronics", T.C. Marshall and D.B. McDermott. (Scully, Jacobs and Sargeant, eds.) Addison Wesley, Vol. 1 (1980). (To Appear).

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR-TR-80-0545	2. GOVT ACCESSION NO.: AD-A086688
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): HIGH POWER SUBMILLIMETER AND INFRARED RADIATION FROM INTENSE RELATIVISTIC ELECTRON BEAMS	5. TYPE OF REPORT & PERIOD COVERED: Final rept. 1 Jan 75 — 31 Dec 79
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): S. P. Schlesinger, T. C. Marshall, P. Diament	8. CONTRACT OR GRANT NUMBER(s): F44620-75-C-0055
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Electrical Engineering, Columbia University, New York, NY 10017	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 2301/A7
11. CONTROLLING OFFICE NAME AND ADDRESS: AFOSR/NP, Bolling AFB, Bldg. 410, Wash DC 20332	12. REPORT DATE: March 1980
	13. NUMBER OF PAGES: 10
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of experiments was performed to test the dependence of superadient power generated by stimulated Raman backscattering (at 2 mm wavelength) upon ripple-field amplitude and length. Experiments were also performed to understand the possibility of using distributed feedback in a collective mode free electron laser. A theoretical study was completed to understand the growth of circular waveguide modes by parametric coupling to cold beam waves, with field gradients included. This is similar to free electron laser configurations to be studied in upcoming experiments.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 088930

ATE
LMED
-8